The influence of cortisol on non-suicidal self-injury with a focus on adolescents

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Abstract

Non-suicidal self-injury (NSSI) is a prevalent behavioral concern among adolescents, characterized by deliberate self-inflicted harm without suicidal intent. While psychological and social factors have been widely examined, increasing attention has turned to the biological underpinnings of NSSI, particularly the role of the hypothalamic-pituitary-adrenal (HPA) axis and its primary hormonal output, cortisol. This paper explores the influence of cortisol dysregulation on the emergence, maintenance, and severity of NSSI in adolescents. Findings indicate that individuals engaging in NSSI often exhibit either blunted or heightened cortisol responses, reflecting maladaptive neuroendocrine adaptations to chronic stress. Neurobiological evidence further reveals that brain regions sensitive to cortisol, including the amygdala, prefrontal cortex, and anterior cingulate cortex, show structural and functional differences in adolescents with NSSI. Additionally, cortisol's effects on memory, cognitive bias, and behavioral reinforcement loops suggest it plays a central role in both the subjective experience of stress and the compulsive nature of NSSI. Recognizing cortisol as a potential biomarker may enhance diagnostic precision and inform the development of targeted, neurobiologically-informed interventions for at-risk youth.

Keywords: NSSI, Cortisol, Adolescents, Hormone Imbalance

Introduction

Non suicidal self-injury (NSSI) is defined as the intentional damage done to the surface of the body without any suicidal intent. A few common methods are cutting, scratching, hitting and skin-scraping. It's mostly prevalent in adolescence wherein 17-60% have reported some NSSI in their lifetime and peaks during the age of 15-17 with a decline in late adolescence (Swannell et al., 2014). Factors like childhood abuse, social media, peer bullying and introduction of NSSI through social gatherings are major contributors. Adolescent females are more likely to engage with NSSI, especially by cutting and males by hitting.

To understand the etiology of NSSI, the hormones related to it have to be analyzed. Cortisol, commonly known as the "stress" hormone, is closely linked to NSSI urges. Cortisol increases the catabolic state of the body by utilizing the energy reserve of the brain and the body (Piarulli et al. 1924). Adolescents who have engaged with NSSI have been found to have a higher cortisol awakening response (Klimes-Dougan et al. 232). Ultimately, this work will contribute to our knowledge on the common cause of NSSI and suggest that measuring cortisol levels can be a quantitative marker of possible NSSI.

Cortisol's effect on NSSI

The primary stress hormone, cortisol, is an important part of the becoming of NSSI. Cortisol is the end-product of the hypothalamic-pituitary-adrenal (HPA) axis (a central neuroendocrine system involved in the regulation of stress, mood, and arousal)

(Groschwitz, R. C., & Kaess, M. (2017)) . The HPA axis is activated when the brain perceives stress and consists of the following three parts:

1) Hypothalamus: Releases Corticotropin-releasing hormone (CRH)
2) Pituitary gland: Releases Adrenocorticotropic hormone (ACTH)
3) Adrenal gland: Releases Cortisol into the bloodstream

Cortisol aids the body in its response to stress by regulating the metabolism and immune responses. HPA dysregulation through blunted or excessive cortisol responses has been shown to be implicated in NSSI, with research suggesting that individuals exhibiting abnormal HPA axis activity often engage in such behaviors (Auerbach et al. 104). Research has supported have reported that blunted cortisol responses to stress may reflect more chronic stress exposure or even adaptative responses to overwhelming stressors (Ouellet-Morin et al. 272). This blunted response could contribute to emotion dysregulation, therefore making it more difficult for an individual to manage stress without behaviors like NSSI. Moreover, the stress response overseen by cortisol can induce feelings of distress, which further leads individuals to fall back on self-injury as a main coping mechanism to deal with intense emotions (Koenig et al. 226).

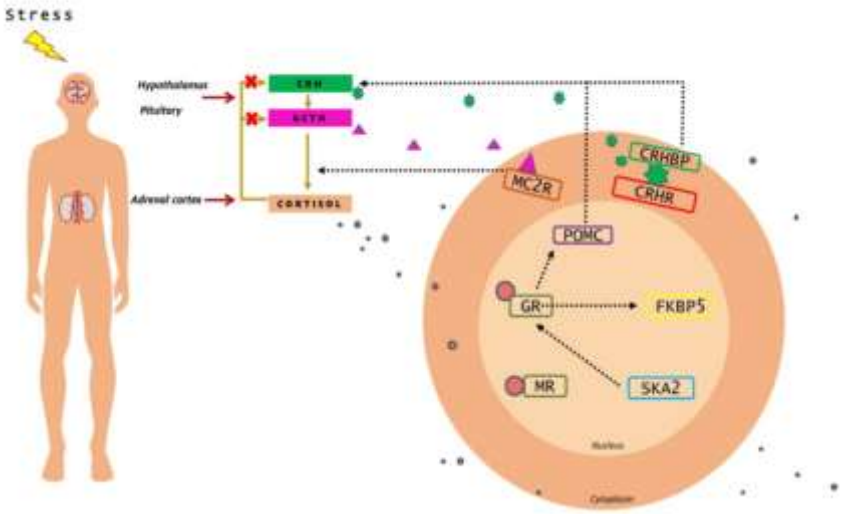

Figure 1: HPA axis components (from Hernández-Díaz et al. 1608)

Figure 1 shows how stress activates the HPA axis. Once the stressor is exposed, the hypothalamus is activated and releases CRH which acts as the primary initiator of the stress response. This causes the anterior pituitary gland to be stimulated. Next, the anterior pituitary gland secreted ACTH which acts as the key messenger targeting the adrenal cortex. Then, the adrenal cortex produces and releases cortisol. Cortisol mobilizes the energy reserves and facilitates an adaptive response to the stress.

Further research into the role of cortisol in NSSI has focused on three domains of measurement:

1) Basal cortisol levels: measured under non stressful conditions (Klimes-Dougan et al. 304)
2) Cortisol reactivity to stress: assesses HPA axis's ability to respond to an acute stressor (Auerbach et al. 104)
3) Chronic cortisol output: cumulative measure of cortisol secretion of extended periods of time (Schreier and Chen 2839)

All the studies have displayed one central finding: adolescents who engage in NSSI showcase a blunted cortisol response to acute psychosocial stressors. A study by Kaess et al. (2012) used the Trier Social Test (TSST) to evaluate cortisol reactivity in female adolescents with NSSI. The study revealed that these individuals had a significantly attenuated salivary cortisol response compared to the healthy controls (Kaess et al. 157). Another study, Reichl et al (2019) examined the cortisol responses during an individual's recollection of childhood adversity. This study had adolescents participating in NSSI as well as their siblings to compare the cortisol levels. The study showed that only those with NSSI had a substantial decrease in the salivary cortisol with heightened baseline cortisol concentration in hair samples. This was even though both the groups reported comparable degrees of negative experiences. These results imply that individuals with NSSI have a distinct HPA axis profile (Reichl et al. 2019).

Psychological Mechanisms Linking Cortisol Dysregulation to Non-Suicidal Self-Injury

To explain NSSI more thoroughly, a psychological framework focusing on experience avoidance, maladaptive emotion management and deficiencies in impulse control, is used. When incorporating the biological stress response systems such as the HPA axis and its byproduct cortisol to explain NSSI, this framework offers a connection between the physiological and psychological pathways for NSSI. Additionally, it also maintains homeostasis in the face of danger. NSSI itself is a coping mechanism that may be facilitated by the

dysregulation in this hormone system, which may profoundly change how people see, understand and react to external or internal stimuli (Piarulli et al. (2023).

Emotional dysregulation is a key part of the psychological effects of cortisol on NSSI. Individuals that frequently engage with NSSI have reported a lower threshold for emotional pain and a propensity to feel emotions more strongly than their peers. Additionally, cortisol has a significant modulatory impact on the processing and regulation of emotions (Koenig, Johannes, et al.). High basal cortisol levels or dysregulated diurnal cycles help promote sensitivity to unpleasant emotional cues. These can exacerbate suffering and interfere with the application of adaptive emotion control techniques. Therefore, even normative stressors can be psychologically empowering due to this, further leading people to use NSSI as a coping mechanism or affect regulation technique. According to Vann der Venne, cortisol acts on the brain regions like the amygdala and the anterior cingulate cortex to reduce both emotion and physical pain reactions (van der Venne et al. 92). Chronic HPA activation, however, also has the potential to desensitize this system and leads to a paradoxical response in whether hyper- or hypo-reactivity to pain is linked to higher NSSI severity. The chronic activation of the HPA axis can lead to its desensitization. Essentially this entails the body's stress-response system to no longer function in a typical or regulated manner. This dysregulation creates a paradox in how individuals who engage in non-suicidal self-injury (NSSI) experience pain. In a few cases, individuals exhibit hyper-reactivity to pain, where they feel pain more intensely, and self-injury becomes a coping mechanism (van der Venne et al. (2013))

Additionally, NSSI has also been linked to reduced heart rate and increased heart rate variability (Koenig et al. 321). Increasing the severity of NSSI predicted higher cortisol responsiveness to pain stimulation (van der Venne et al. 92). These results also support the idea that NSSI is a psychologically persuasive coping mechanism. It indicates that the people with chronic NSSI may have unique physiological profiles that can represent the long-term adaptations to emotion and physical stress.

Moreover, cortisol affects not just the immediate control of emotions but also the consolidation and retrieval of memories (Shields, Grant S., et al). Both processes are essential for psychological resilience and vulnerability. In contrast to boosting the consolidation of emotionally salient memories (especially negative ones) stress induces cortisol production which can interfere with the recovery of explicit memories. Individuals who have experienced trauma or adversity as children may develop a cognitive bias toward memories of threat (Shields et al. 636). This makes pressures in everyday life seem more important. In Reichl et al, 2019 teenagers with NSSI were asked to recall negative childhood experiences and their cortisol levels sharply decreased during that interview. This finding was interpreted as the downregulation of the HPA axis in the face of emotionally painful recall (Reichl et al. (2019)).

An ingrained psychological defense mechanism may be reflected in this maladaptive stress response, which blunts emotional arousal to deal with unpleasant content at the expense of healthy emotional processing. According to Reichl et al. (2019), such dysregulation may eventually prolong cycles of emotional repression, avoidance, and dependence on NSSI for affect modulation.

Cortisol dysregulation can also interact with negative self-schemas and cognitive distortion. The increased attention to negative emotional cues and the difficulty disenganging from them is linked to an elevated cortisol level. This cognitive pattern closely resembles the persistent thinking and self-critical internal dialogue seen in self-harming individuals. The vicious cycle of negative affect and impulsive behavior may be reinforced in adolescents with a higher cortisol awakening response (CAR) because they are more likely to catastrophize and perceive minor slights from the others as a more serious offence or danger (Reichl et al. 104460). According to Kaess et al. 2012, there appears to be a mismatch between the physiological and subjective experience of stress because a reduction in seen or reported emotional discomfort did not coincide with decreased cortisol reactivity during social stress activities. This mismatch may also exacerbate emotional ambiguity and undermine an individual's trust in internal cues. This could further encourage the use of external techniques like NSSI to control the psychologically uncomfortable conditions (Kaess et al. 465).

Lastly, the psychological environment can influence the relationship between cortisol and NSSI (Kaess et al. 465). Particularly early caregiving, peer dynamics and social support have a higher impact on NSSI development. According to attachment theory, the stress system may become chronically activated because of irregular or insecure attachment—especially during critical developmental windows (Gunnar and Herrera 210). Children may develop maladaptive self-regulation techniques inclusive of self-harm if caregivers do not co-regulate. As a biological messenger that converts environmental stress into psychological experience, cortisol acts as a mediator in this process (Miller, Chen, and Parker 959). Hence, the psychological profile linked to chronic NSSI is characterized by feelings of powerlessness, interpersonal distrust and emotional numbness. All of these may be reinforced by dysregulated cortisol patterns (Koenig et al. 189)

In conclusion, the relationships between stress perceptions, emotional intensity, cognitive interpretation and behavioral coping help define the psychological aspect of cortisol's impact on NSSI. To influence how people experience and react to psychological distress, cortisol interacts with personality factors, traumatic pasts and developmental contexts. Making individuals aware of these mechanisms, we may be able to better adapt psychological interventions to each person's unique neuroendocrine profile. This will result in a more individualized and integrate approach to care for those who are at a risk for self-harm

In non-suicidal self-injury (NSSI), the behavioral ramifications of cortisol dysregulations are complex. They can impact impulsivity, reward processing, pain perception and self-control mechanisms (Koob and Le Moal 29). As adolescence is a developmental stage which is characterized by heightened emotional liability and risk-taking tendencies, cortisol's involvement in irregulating the behavioral reaction to stress becomes extremely evident (Gunnar and Herrera 210). The arousal levels are affected by cortisol as well as the cognitive assessment of stress. This can in turn affect how people behave under emotional taxing or overpowering circumstances. Hence, these behavioral adaptions may show up as recurrent self-harming behaviors which would be used to restore psychological balance, especially in cases of persistent dysregulation of the HPA axis (Koenig et al. 189). It is also important to notice the cortisol-mediated behaviors to create interventions that can successfully break the maladaptive behavioral loops supporting NSSI.

Changes in the processes of pain of an individual who engages with NSSI is one of the most well-established behavioral characteristics (Koenig, Julian, et al). Adolescents and young adults that participate in NSSI have reported lower pain sensitivity and a higher pain threshold during self-inflicted harm. Cortisol's impact on the endogenous opioid system and nociceptive processing helps in explaining this. Due to the anti-nociceptive actions mediated by the limbic system and the periaqueductal gray, acute increases in cortisol are generally linked to a higher pain tolerance.

Contrastingly, the neuroendocrine response to pain may also change if cortisol signaling becomes persistently dysregulated. This is frequently observed in those who experience early-life trauma. Teenagers who have severe NSSI urges and engagements have shown greater cortisol reactivity to experimental thermal pain, which paradoxically coincided with decreased sympathetic activation and elevated parasympathetic tone, (Van der Venne et al's 2023). This data implies that cortisol may decouple the subjective experience of pain from physiological arousal, thereby it also facilitates engagement in NSSI by reducing the behavioral deterrents of physical discomfort.

Moreover, cortisol affects the behavioral patterns of emotional regulation in addition to pain sensitivity (Koenig et al. 189). This is frequently manifested as affect-driven impulsivity in the setting of NSSI. Impulsivity in self-harm is a state-dependent response to affective overload, which is a frequently made worse by stress. Cortisol has a role in this behavior by lowering inhibitory control, problem-solving ability, and prefrontal brain function under stress (Arnsten 410).

Individuals with cortisol blunting or hyperreactivity may find it difficult to control automatic behaviors such as self-harming, under stress especially if these behaviors have been reinforced as useful mood regulation techniques in the past. According to Kaess et al. (2012), there appears to be a disconnect between behavioral arousal and physiological stress signaling, as adolescents with NSSI had decreased cortisol responses to psychosocial stress without commensurate decreases in negative affect. This dysregulation may make behavioral outbursts more likely because the absence of appropriate endocrine feedback prevents a calming of the system once the stressor has passed (Kaess et al., 2012).

Moreover, NSSI's behavioral reinforcement loop is linked to cortisol. Self-harm may start out in a conscious and intentional attempt to control unbearable affect; however, it frequently develops into a habitual activity (Koenig et al. 189). This is then sustained by negative reinforcement, which notably lowers the emotional arousal. Every successful act of self-harm that reduces the emotion distress in an individual further reinforces the same practice (Hooley and Franklin 428). For example, situations where cortisol levels are insufficient to naturally reduce stress. According to a study by Reichl et al. (2024), which followed teenagers for two years, early adversity and cortisol secretion patterns (such diurnal slope and cortisol awakening response) interacted to predict different behavioral trajectories of NSSI. Adolescents with severe adversity and elevated cortisol levels exhibited longer but steadier behavioral recovery while those with low adversity and high cortisol levels showed a quick initial behavioral improvement that was not durable (Bunea, Szentágotai-Tătar, and Miu article 1274). Therefore, this implies that cortisol influences the frequency and persistence of NSSI episodes by reflecting both present stress and long-term behavioral adaption (Reichl et al, 2024)

The behavioral interpretations of adolescents in social interactions and interpersonal pleasures may also be impacted by the cortisol dysregulation (Miller and Chen 848). Individuals that have an increased CAR or elevated basal cortisol may be more sensitive to social threat cues which are strong inducers of NSSI (Reichl et al. 104460).

Hypervigilance can also show up as impulsive self-harm engagement especially in responses to perceived or actual social disengagement or impatience. Importantly, it has been demonstrated that adolescents with unstable attachment histories and prolonged familial stress conditions can modify their HPA axis programming which can lead to a heightened behavioral sensitivity to social rejection. According to Reichl et al. (2016), adolescents who had experienced emotional abuse and neglect in the past showed steeper diurnal cortisol slopes if they participated in NSSI. This could be a result of hyperarousal in reaction to everyday stressors, which can lead to maladaptive behaviors.

Additionally, it is also important to note that some behavioral therapies are effective but may vary according to cortisol profiles. Some adolescents with cortisol hyper-reactivity could need trauma informed strategies that can address physiological hyperarousal (D'Andrea et al. 187), but those with cortisol hypo-reactivity might benefit from dialectical behavioral therapy (DBT) modules which emphasize distress tolerance and arousal modulation (Stepp et al. 333). Emerging precision psychiatry frameworks that advocate for individualized

therapies based on unique neurobiological characteristics lend support to this behavioral-cortisol matching idea (Williams 472). As a stable and state-sensitive biomarker, cortisol has the potential for directing behavioral treatment choices.

In summary, cortisol has a wide range of behavioral effects in the maintenance of NSSI. It ranges from regulation of stress and pain responses to promotion of the emotion-driven impulsivity and repetitive nature of self-harm. In case of a successful intervention for NSSI, one must consider both the behavioral manifestations as well as the underlying biological conditioning. The hormone has a reciprocal relationship with behavior. It influences it as well as gets influenced by it.

Neurobiological correlates of cortisol dysregulation in NSSI

In a neurobiological lens, cortisol has an impact on NSSI through the intricately linked pathways that involve both the structural and functional changes in particular brain areas (van Harmelen et al. 170). These include areas essential for control, emotional regulation, pain processing and perception of threat (McEwen and Wingfield 105). Cortisol interacts with the glucocorticoid and mineralocorticoid receptors (both highly expressed in the hippocampus, amygdala, prefrontal cortex, and anterior cingulate cortex (ACC)), thus having a profound impact on the central nervous system (Lupien et al. 434). These brain regions are also found to be linked to the pathophysiology of NSSI, indicating that the structural and functional alterations supporting the emergence and maintenance of self-harming behavior may be influenced by cortisol dysregulation (van Harmelen et al. 170).

Teenagers and young adults who participate in NSSI have notable changes in their brain structures.

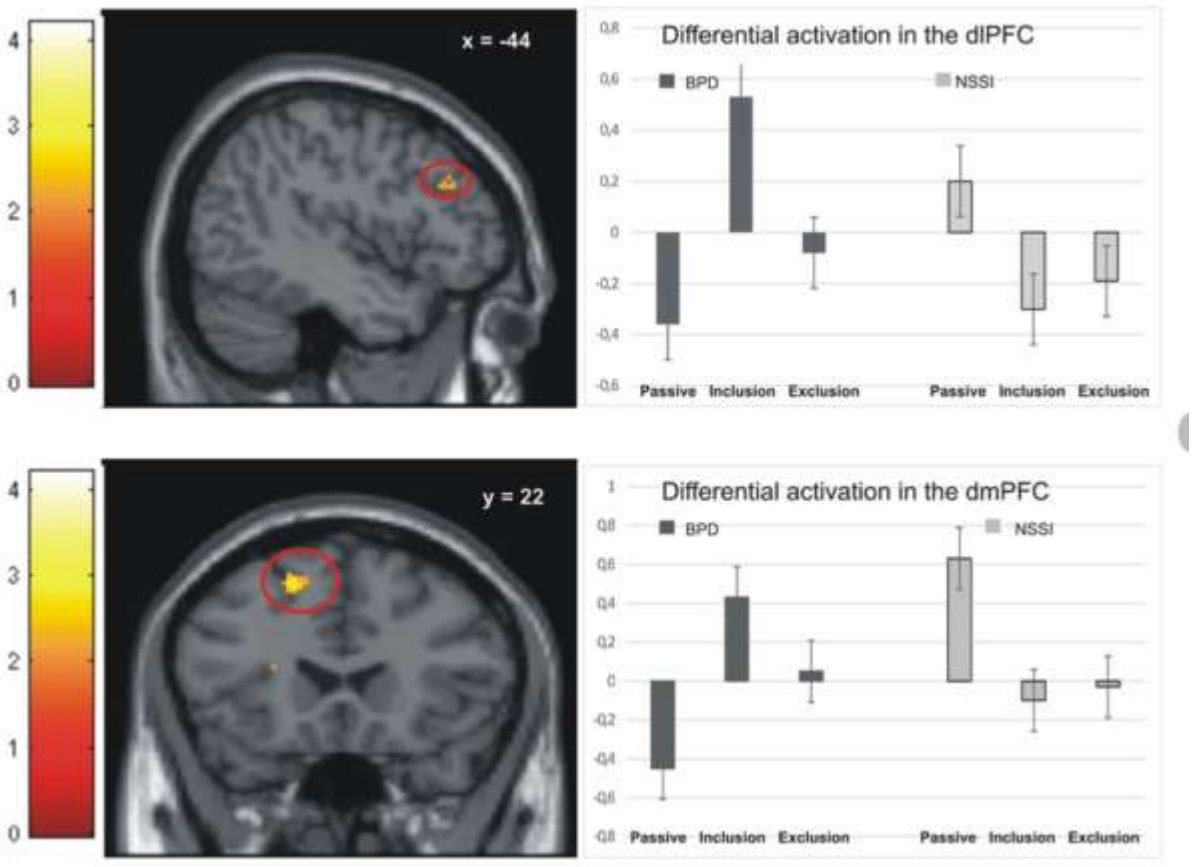

Figure 2: Activation in the dorsolateral prefrontal cortext (diPFC) and dorsomedial prefontal cortex (dmPFC) in non-suicidal self-injury (NSSI) Image taken from Brown et al. article 267

Among the most consistently implicated regions of the brain are the dorsolateral and ventromedial prefrontal cortices. These areas are essential for the top-down regulation of emotional and behavioral responses. These individuals show the reduced gray matter volume in these regions, this may compromise their ability to exert cognitive control over impulsive and affect-driven behaviors. In support of this, the study Brown et al 2017 demonstrated through functional MRI that adolescents with NSSI showed altered activation patterns in the

dorsolateral and dorsomedial prefrontal cortices during emotionally charged social interactions, highlighting disrupted engagement of neural circuits responsible for emotional regulation (Brown et al. article 267).

Moreover, the dysregulation of cortisol also compounds these neural vulnerabilities. Chronic elevations in basal cortisol or exaggerated CAR are known to exert neurotoxic effects on prefrontal regions. This can impair synaptic plasticity hence progressively degrade the executive functions critical for inhibiting maladaptive behaviors such as NSSI (Liston et al. 7870).

Additionally, the amygdala which is involved in danger detection and emotional salience has also been repeatedly linked to both stress and emotional dysregulation. Functional MRI investigations revealed that those with frequent NSSI engagements exhibited amygdala hyperactivation in response to the unpleasant emotional stimuli (Plener et al. article 1). This is associated with increased affective intensity and impulsive reactions. Cortisol normally regulates amygdala activity via feedback inhibition. However, when cortisol signaling becomes chronically dysregulated, either because of hyperactivation due to chronic stress or blunted responses due to the allostatic overload, this inhibitory control is compromised (McEwen and Wingfield 105). The result is the amygdala becoming overly sensitive to emotional stimuli, especially those linked with rejection, abandonment or perceived failure (van Harmelen et al. 170). The anterior cingulate cortex (ACC) is closely associated with the amygdala and is involved in error detection, emotional awareness and even conflict monitoring (Etkin et al. 85). According to research studies, individuals who engaged in NSSI had lowered ACC activity during emotional regulation tasks (Westlund Schreiner et al. 47). These could then contribute to the difficulties in detecting or articulating emotional states, this condition is called alexithymia (Norman et al. 733). Cortisol's relationship with the ACC is complex. Acute stress can increase ACC activity and encourage adaptive alertness, chronic cortisol exposure appears to reduce ACC reactivity. This hypoactivation has also been linked to a decreased ability to assess emotional context and choose appropriate behavioral responses, allowing maladaptive coping techniques such as self-harm to be used (Westlund Schreiner et al. 47).

Moreover, the hippocampus is another important structure in the cortisol NSSI neurocircuit. The hippocampus offers negative feedback to the HPA axis, thereby it slows the cortisol release after stress exposure (McEwen 105). This feedback system is frequently compromised in adolescents who have experienced chronic stress or repeated trauma, which are both disproportionately represented in NSSI groups (Teicher et al. E563). Hence, it slows the cortisol release after stress exposure.

The neurodevelopmental timing also complicates these relationships. Adolescence is a vital period for the brain growth and synaptic pruning, both are susceptible to hormonal modulation (Blakemore & Choudhury, 2006). Cortisol affects the progression of prefrontal cortex maturation and myelination. These are both required for impulse control and executive functioning. For those individuals who have persistent HPA axis dysregulation, these processes may be delayed or abnormal (Lupien et al. 434). This results in an imbalance between emotional reactivity and cognitive control.
This developmental asynchrony has been proposed as a basic neurobiological vulnerability for NSSI. The capacity to feel and react outperforms an individual's capacity to reflect and inhibit. Reichl et al (2019) shows more evidence for the same. It revealed that teenagers with NSSI showed aberrant cortisol responses while recalling childhood trauma. This implied that the traumatic events have caused long term neuroendocrine and neurocognitive changes in brain.
The combination of neuroimaging as well as the endocrine indicators begin to reveal various NSSI phenotypes. Each of these have their own neural signature. Some individuals might possess increased cortisol reactivity and amygdala hyperactivity, which may indicate a pattern of emotional hyperarousal and threat sensitivity. Others, however, may show lowered cortisol responses, decreased ACC activation and impaired hippocampal feedback. This may indicate a pattern of emotional numbness, poor insight and more stress habituation. These neurobiological subgroups have significant implications for customized treatment strategies. Interventions that are aimed at amygdala hyperactivity like emotion focused therapy or mindfulness-based stress reduction may be a more effective method for those who are hyperactive. Contrastingly, interventions that aim at enhancing emotional awareness and strengthening top-down control mechanisms would be better for those with cognitive affective blunting.

Conclusion and Summary:

In summary, NSSI is strongly influenced by the complex interactions between cortisol and the behavioral, psychological and neurobiological pathways of the body. The HPA is an important aspect when it comes to NSSI's manifestation as its dysregulation may cause for a direct increase in the urge for NSSI. Neuroimaging studies also reveal abnormalities in brain regions that are critical for emotional regulation, including the amygdala, prefrontal cortex and hippocampus. NSSI is particularly highly manifested and maintained in adolescents due to the hormonal imbalance and brain development that occurs during that period. In addition to that, individuals that engage with NSSI report of altered pain perceptions, possibly due to the disruptions caused to the endogenous opioid system. Emotional dysregulation also remains a core feature, the heightened cortisol reactivity correlating with the difficulty in managing intense feelings allow NSSI urges to be developed and used as a coping mechanism. Together, these findings suggest that NSSI arises from a convergence of biological vulnerabilities, psychological challenges and developmental influences. Further possibilities for research include understanding how to help individuals control or manipulate cortisol levels in order to manage or refrain from the engagement with NSSI. Moreover, research into regulating the perception of pain for those who have already engaged in NSSI and finding out how to return those receptors to their functions before is also pertinent.

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